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Academic and research capacity development in Earth observation for environmental management

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Abstract

Sustainable environmental management is one of the key development goals of the 21st century. The importance of Earth observation (EO) for addressing current environmental problems is well recognized. Most developing countries are highly susceptible to environmental degradation; however, the capacity to monitor these changes is predominantly located in the developed world. Decades of aid and effort have been invested in capacity development (CD) with the goal of ensuring sustainable development. Academics, given their level of freedom and their wider interest in teaching and knowledge transfer, are ideally placed to act as catalyst for capacity building. In this letter, we make a novel investigation into the extent to which the EO academic research community is engaged in capacity development. Using the Web of Knowledge publication database (<http://wok.mimas.ac.uk>), we examined the geographical distribution of published EO related research (a) by country as object of research and (b) by authors' country of affiliation. Our results show that, while a significant proportion of EO research (44%) has developing countries as their object of research, less than 3% of publications have authors working in, or affiliated to, a developing country (excluding China, India and Brazil, which not only are countries in transition, but also have well established EO capacity). These patterns appear consistent over the past 20 years. Despite the wide awareness of the importance of CD, we show that significant progress on this front is required. We therefore propose a number of recommendations and best practices to ease collaboration and open access.

Keywords: capacity development, Earth observation, best practice

1. Introduction

Sustainable environmental management is one of the key development goals of the 21st century. EO is increasingly recognized as a key tool for providing large-scale, up-to-date data about Earth surface processes to aid management decisions. There is growing awareness of the need for developing indigenous capacity across all nations in the application of satellite remote sensing. The vulnerabilities of developing countries to the impacts of climate change and

environmental degradation have been highlighted many times (e.g. Ayers and Dodman 2010, Patt *et al* 2010, IPCC 2007). Yet many such countries currently lack the necessary scientific and technical capacity within their research communities to fully assess possible future impacts. They are less able to conduct the multi-disciplinary studies needed to fill gaps in understanding climate change impacts at regional and local levels, or to fully take advantage of the global data sets now widely available (DeFries *et al* 2007).

While developing countries face the most pressing threats from environmental degradation, the best EO capacity to monitor these changes lies in the developed world. The aim of this letter is therefore to examine whether this ‘capacity versus needs’ polarization also occurs in the academic EO literature. This is achieved by exploring publication patterns between developed and developing countries. Notably, we query whether EO research, conducted in or about a given country, involves in-country authors. We first explore this issue broadly by examining the proportion of EO research published about a particular country compared to the proportion of in-country affiliated authors associated with that research. Secondly, by utilizing the field of forestry as a test case, we then explore geographically the patterns of authorship provenance and countries as research focus. Our discussion considers whether (and if so how) EO research has responded to meet the developing world’s EO CD needs, and examines wider implications for development and policy-making. We conclude by proposing three strategies for promoting academic and research CD in the EO sector. In section 2, we introduce briefly the development of CD thinking, and discuss the importance of academic-led CD in Earth Observation.

2. What is capacity development?

Capacity is defined as the ‘ability or power to do, understand or experience something’ (Oxford English Dictionary 2010). ‘Capacity building’ involves strengthening particular scientific or technical abilities and resources in individuals, institutions or infrastructure (Wignaraja 2009). Some authors and institutions advocate the use of the expression ‘capacity development’ in recognition of the existing knowledge or infrastructure available (Linnell 2003, Lusthaus *et al* 1999, Wignaraja and Yocarini 2008). Some have argued that both expressions narrow focus to mainstream development strategies (Fisher 2010). In this letter however, CD is intentionally loosely defined to be inclusive of a broad variety of development focused strategies. While most frequently referring to activities conducted in developing countries, CD is not country- nor sector-specific. In this letter, we focus on academic and research CD in the EO sector.

A summary of EO activities pertaining to CD has recently been published (Group on Earth Observation, GEO 2006) and a key highlight of this report is the demonstration that the success of EO related CD depends on the building of capacity in all (not only one) of the following three dimensions: human, institutional and infrastructural. Capacity and performance is a result of the interactions within and between these dimensions. Examples of such successful EO sector CD within the developing world are found in the fields of weather forecasting and disaster monitoring. CD strategies in these fields were primarily driven by the importance of EO technologies for food security and livelihood resilience (Quansah *et al* 2010, Lewis *et al* 2010). The success of projects such as those by Jason *et al* (2010) partly stems from their clear definition of technical yet specific goals, realistic objectives, and perhaps most importantly, from a long-term commitment to projects and associated CD.

Other EO fields have recently received attention, notably that of forest mapping. Such attention has been driven largely by both the United Nation’s Food and Agriculture Organization’s (FAO) increasing reliance on remote sensing to produce the Forest Resource Assessments (FAO 2010b), and an increased attention to the need to monitor Reduced Emissions from Deforestation and Degradation (REDD) from developing countries. REDD has been proposed as a global policy instrument for mitigating climate change (Gibbs *et al* 2007, Obersteiner *et al* 2009).

Within a given country, CD can be driven by internal and external pressures or incentives. While some instances of internally led CD activities (conducted independently from external donor activity) can be found (Eade and Williams 1995, Baser and Morgan 2008), foreign aid programmes have had a predominant role to play in CD (Caplan 2004). Successes have ensued from such foreign aid programmes, but some associated CD strategies have led many low income countries to become dependent on foreign donors. Results were often constrained by a project’s life span, which ultimately led to disempowering the very countries that were meant to benefit from the development (Stephen 2006). Current best practice advocates empowerment: developing countries should design and implement development approaches themselves (Wignaraja and Yocarini 2008, Wignaraja 2009, Brinkerhoff 2009), allowing them to articulate a vision of development that best meets their own situation and beliefs. This shift has taken place largely as a result of the recognition that CD must operate at all levels within a country if donor intervention is to have any lasting long-term impact (OECD 2006, 2008, Wignaraja and Yocarini 2008, Samoff and Carrol 2004).

2.1. Academic and research capacity development

‘... Research in and with developing countries should—and indeed must—lead to the strengthening of their research capacity.’

—Swiss Commission for Research Partnerships with Developing Countries (KFPE) (1998).

Academic and research CD, and the associated CD necessary to support it, is key to engaging developing country researchers in global academic discourse, strengthening their own skills and confidence in conducting internationally recognized research (Crossley and Holmes 2001). The GEO Capacity Building Strategy (GEO 2006) has identified a need for close collaboration between countries to strengthen institutions and infrastructures, beyond technological and capacity development in developing countries. This does not simply mean developed and developing country partnerships, but also partnerships between developing countries. For example South Africa, Algeria and Nigeria have greater capacity than most of the rest of sub-Saharan Africa with regards to EO expertise (Jason *et al* 2010, Gottschalk 2010), and could take the lead in partnering with other countries in the region to develop regional EO capacity. Brazil has also taken on a leading role in South–South partnerships in a number of areas including EO research (Peter 2009). This is illustrated by their commitment to providing free EO data to Latin American

Table 1. Selected 68 countries and associated country codes (in alphabetical order).

ARG	Argentina	GHA	Ghana	MOZ	Mozambique	RWA	Rwanda
AUS	Australia	GRC	Greece	MUS	Mauritius	SAU	Saudi Arabia
BGD	Bangladesh	GTM	Guatemala	MWI	Malawi	SWE	Sweden
BLZ	Belize	GUY	Guyana	MYS	Malaysia	TCD	Chad
BOL	Bolivia	IDN	Indonesia	NER	Niger	THA	Thailand
BRA	Brazil	IND	India	NGA	Nigeria	TUN	Tunisia
BWA	Botswana	IRQ	Iraq	NLD	Netherlands	TUR	Turkey
CAN	Canada	ISR	Israel	NOR	Norway	TZA	Tanzania
CHL	Chile	ITA	Italy	NPL	Nepal	UGA	Uganda
CHN	China	JPN	Japan	PAK	Pakistan	UKR	Ukraine
COL	Colombia	KEN	Kenya	PAN	Panama	URY	Uruguay
DEU	Germany	LBY	Libya	PER	Peru	USA	United States
DRC	Democratic Republic Congo	MAR	Morocco	PHL	Philippines	VEN	Venezuela
EGY	Egypt	MDG	Madagascar	POL	Poland	VNM	Vietnam
ESP	Spain	MEX	Mexico	PRY	Paraguay	ZAF	South Africa
FRA	France	MLI	Mali	ROM	Romania	ZMB	Zambia
GBR	United Kingdom	MNG	Mongolia	RUS	Russian Federation	ZWE	Zimbabwe

and Africa as part of the China Brazil Earth Resources Satellite (CBERS) programme (Ferreria and Camara 2008).

As a broad generalization, scientists in developing countries are increasingly becoming concerned about external agencies, institutions and individual researchers operating in their countries with limited regard for local CD or alignment with national and regional development priorities (Samoff and Carrol 2004, Jallade *et al* 2001). Regional or country-specific EO research activities that cover developing nations are often not conducted in partnership with local research groups or institutions. This is understandable given that many EO activities, by definition, are done remotely.

To gauge the extent of this problem, we looked at one aspect of research output, namely research publications in peer-reviewed journals, firstly by searching for papers published by a range of countries defined by their economic status and secondly by investigating the geographical distribution of authors compared to countries of research focus. Notwithstanding the obvious limitation that we only cover published research (much in-country research may not find its way to journals or may be conducted by organizations who have no goals for publishing in this way) we believe this analysis provides a valuable perspective on the effectiveness of EO capacity development.

3. Methodology

3.1. An assessment of publication output

Approach A. Articles containing any of the following terms were extracted from Web of Knowledge (WoK) (<http://wok.mimas.ac.uk>), for the period from 1971 to present (Oct 2010): remote sensing, Earth Observation, satellite image, ALOS, Landsat, and MODIS. Our intent was not to develop an exhaustive database of EO research, but rather to generate a representative overview of EO research. This time period was selected as EO emerged as a discipline around the 1970s. Articles related to meteorology, atmospheric science, oceanography and marine science (using the Boolean NOT option) were excluded.

After these initial search criteria were defined, a list of more than one third of the world's (68) countries was created. Our selection, presented in table 1, aimed at being representative of a broad spectrum of economic development status. Countries falling within each one of the World Bank's 4 economic status categories (World Bank 2010) were selected ensuring a fair distribution of countries in each of the categories (low, low-middle, upper-middle and high income). Once this list was generated, the name of each country was added as the final criteria to the search terms listed above. Using the analysis feature within the WoK, we then quantified the number of articles per country and the number of articles per country with the country's name also appearing within the author(s)' address. This was repeated for all 68 countries.

3.2. Investigating geographic trends

Approach B. While Approach A allows an assessment of the proportion of papers written about a particular country with an in-country author involved, it does not allow to explore changes in practices over time in EO-specific CD, nor does it enable us to investigate and visualize the geographical distribution of authorship (including the division between first and subsequent authors) compared to countries of research focus. To achieve this, a similar selection approach to that described above was adopted, with two differences. (a) Given the size of the database generated, we constrained our search to forestry, a highly topical research area. In addition to the terms listed in Approach A, the terms forest* or woodland* (* as wildcard) were also used to extract articles. All conference proceedings were excluded, our aim being to explore the extent of collaboration occurring throughout the research process (from design to peer-reviewed publication). Irrelevant papers accidentally included (e.g. from chemistry, zoology, medicine) were also manually filtered out. (b) To explore whether CD progress has been made in this area, two time periods were considered. The inclusion of CD within the international development agenda is relatively recent and can be traced back to approximately 20 years ago (Wignaraja and Yocarini 2008, Wignaraja 2009). The periods considered here,

namely 2005–10 and 1990–5 inclusively, were selected to fall well within this timeframe.

Using a random number generator, the selected records were then sampled from the searches, using the record number as a unique reference. A sample size of 20% was generated ($n = 474$ for 2005–10, $n = 87$ for 1990–5). For each record, the following information was recorded (a) the country, countries or region(s) in which the research was conducted (b) all authors' country affiliation (listed in the address field for each author). Where more than one address was listed for an author, the first one was selected. Because remote sensing studies tend to lend themselves to large-scale studies, some papers focused on many countries or even on whole regions or continents. Where papers researched multiple countries, each country was included as an individual entry. The results of these searches were then loaded into ArcMap to allow a visual interpretation of the trends in research patterns (figure 3). Choropleth maps were created using 4 frequency classes: less than 1% (highlights those countries that occur particularly infrequently, maybe only once or twice), 1–5%, 5–10% and greater than 10%. While a 10% threshold may seem low, it actually represents a strong degree of dominance in the results and a significant volume of research output and interest, with very few countries exceeding 10%.

4. Results and discussion

Our selected list of 68 countries is presented in table 1 and our results from Approach A (section 3.1) are presented in figures 1 and 2. Figure 1 presents our results on a country by country basis, while figure 2 shows averages and standard deviations per economic status categories. Both figures show that EO research conducted about a low income or lower-middle income country is much less likely to have an in-country author than research conducted about an upper-middle or high income country. We nevertheless found three anomalous countries: China, India and the USA. While these were excluded from figures 1 and 2, they are further discussed below.

Relative to countries within the same economic status categories, China and India had an anomalously high number of in-country authors relative to the total number of papers published about those countries (79% and 85% respectively). Academically, both China and India stand out compared to other developing countries. They have a significant internal publishing communities illustrated by a healthy number of journals such as the *Journal of the Indian Society of Remote Sensing* or the *Chinese Journal of Atmospheric Sciences*, which target predominantly within country scientists. Most articles in these journals are composed and read almost exclusively by indigenous scholars. The availability of facilities and infrastructure for journal printing and distribution has most likely contributed significantly to the development of these flourishing publishing communities. Also, as countries in transition, both countries have already developed in-house internationally influential and world-leading EO capacity.

The low number of USA-based authors relative to the total number of papers published about the country itself (58%) represents our third anomaly. This result, somewhat

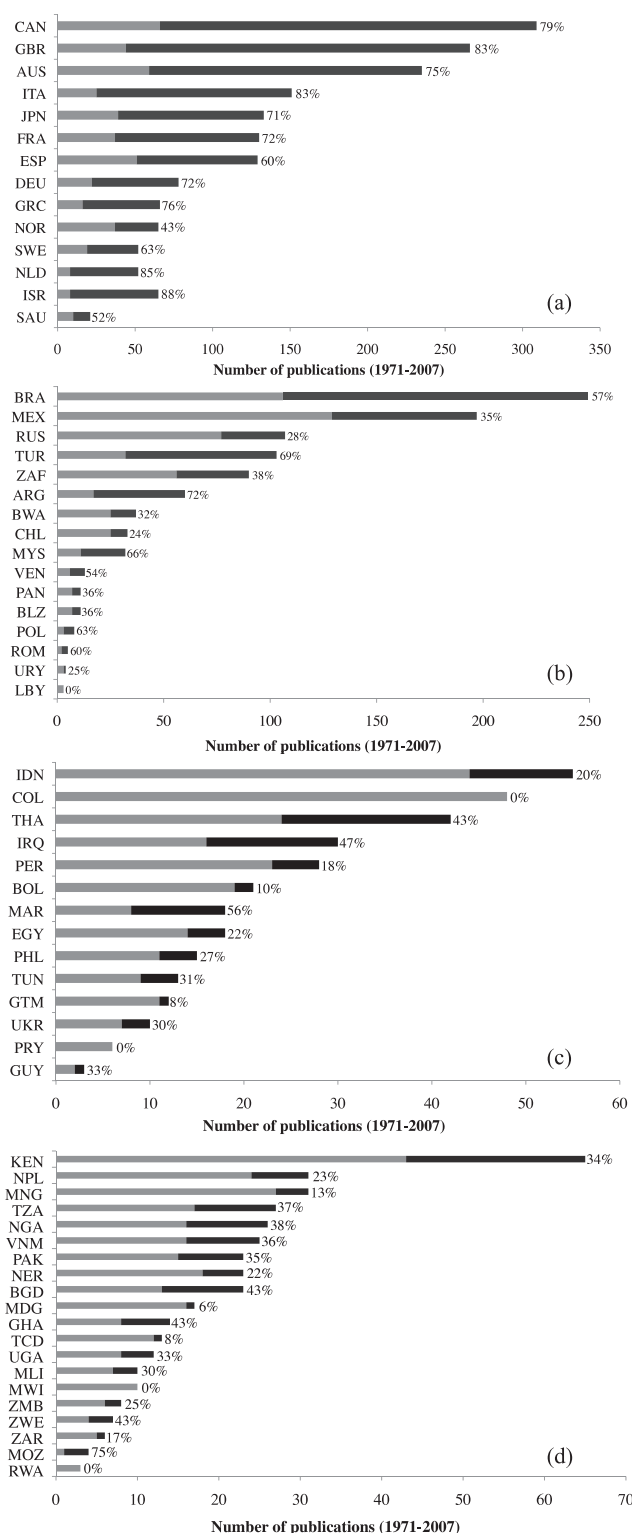


Figure 1. Number of publications for (a) high income, (b) upper-middle income, (c) lower-middle income and (d) low income countries. Total bar length indicates the total number of publications about the country. The black section indicates the number of papers with the country listed in the author address field. The percentage of in-country affiliated authors compared to the total number publications about that country is given at the end of each bar. Publications written about high and upper-middle income countries have a higher proportion of in-country authors compared to papers written about lower-middle and low income countries.

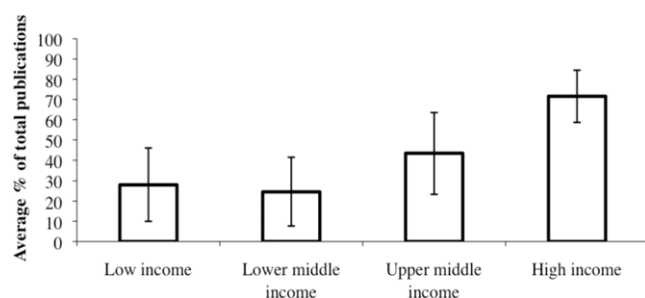


Figure 2. Average (with standard deviation) proportion of articles with in-country authors grouped by World Bank income class. High income countries are almost twice as likely to have an in-country author as low and lower-middle income countries.

unexpected, and may be a consequence of many USA 'Address' fields listing US States only, rather than the country itself. As such, several in-country authors may have been excluded from the analysis.

The results highlighted by Approach A are further reinforced by those of Approach B (section 3.2). Between 2005 and 2010, 44% of EO forest related research sampled was conducted about developing countries (figure 3). However, authors affiliated with developing country institutions account for only 20% of total authorships. These figures drop to 29% and 3% respectively if India, China and Brazil are excluded. When first authorship alone is considered, less than 1% of authors are affiliated with developing country institutions.

Our Approach B results also show Brazil as an anomaly, alongside India and China. Brazil was the country of focus for 9% of research studies sampled, and accounts for 5% of total authors, a proportion dramatically higher than most developing countries. We did not investigate whether a particular author was writing about a particular country, but this does seem to suggest that at least some of the research papers written about Brazil had a Brazilian author, a situation that is not repeated in any other developing country. The consistent efforts, funding and collaborations spearheaded by INPE (National Institute of Space Research) have placed Brazil's EO community well above those of other developing, and some developed, countries, and have led to the prominence of Brazilian scientists within EO research.

For 1990–5, developing countries represented 25% of countries researched, but only 8% of first authorships. If India, China and Brazil are excluded these figures drop to 12% and zero. Figure 3 clearly shows that there has been a change in emphasis about where EO research has been conducted over the last 20 years, with a much greater shift towards southeast Asia, Latin America and Africa. While research conducted between 2005 and 2010 studies a greater range and proportion of developing countries, developing country researchers still represent a small fraction of the total number of authors. This trend in under-representation has not altered over the past 20 years. Figures 3(a) and (b) highlight a noticeable dearth in Africa and southeast Asia. Despite the rise in the importance of CD, there seems to have been no corresponding rise in authorship from developing country researchers (while based in their home institution) over this period. It is acknowledged

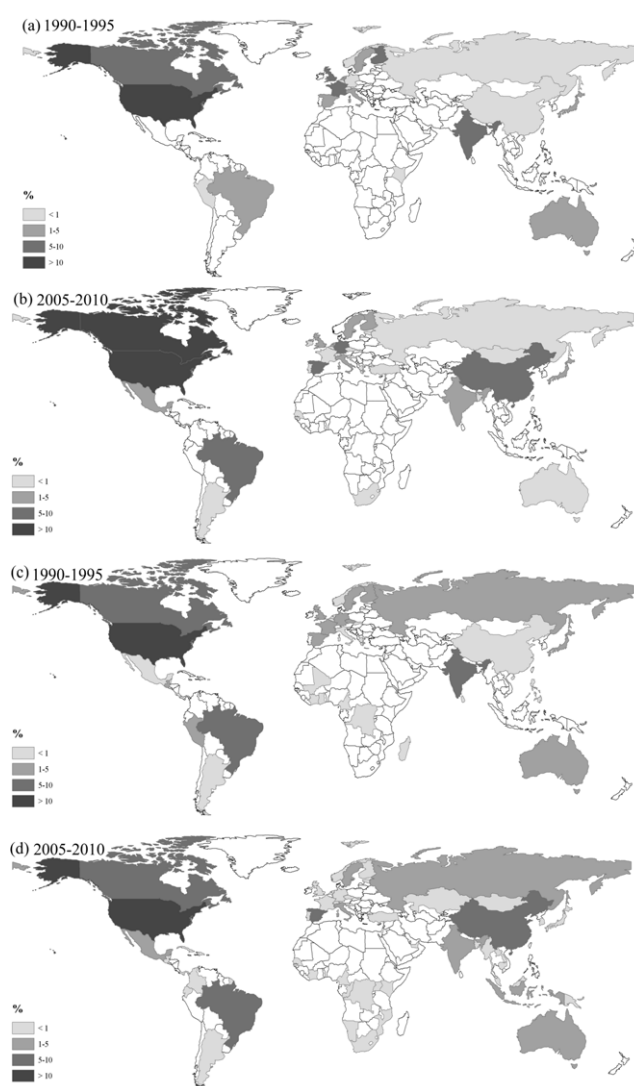


Figure 3. Country affiliation of authors for (a) 1990–5 and (b) 2005–10. Geographical location of research conducted (c) 1990–5 and (d) 2005–10. USA dominates EO research with 30% and 50% of total authorships (1990–5 and 2005–10 respectively). Overall, gaps in authorship are clearly noticeable over Africa and southeast Asia, despite the increase in the number of countries in these regions where research is conducted.

that figure 3(c) perhaps overstates how much research was being conducted in Africa during this period, as the countries in West Africa are all from one paper that conducted a region-level analysis, while the African countries represented in figure 3(b) are all from different studies. Nonetheless the numbers remain striking.

5. Discussion and recommendations

5.1. Educational research partnerships, capacity building and international development assistance

For established researchers in the Global North to best contribute to the development of those countries that lack EO expertise it is essential that they compel themselves to partner with local researchers. Such partnerships must

form at the beginning of a research project and continue throughout the research process. There is a need to develop indigenous capacity to stop the culture of dependency on foreign institutions. The strong emerging economies (e.g. Asian Tigers) have invested heavily in scientific and technical education and training (Green 1999, Morris 1996) and this is partly apparent in our results. In recent years, about a quarter of donor aid, more than US \$15 billion per year, has gone into technical co-operation, the bulk of which is aimed at CD (OECD 2006). However evaluation results confirm that development of sustainable capacity continues to be one of the most difficult areas of international development practice (FAO 2010a, Lusthaus *et al* 1999, Horton 2002, Horton *et al* 2003, Gorgens and Kusek 2009).

With so much emphasis on access to basic education throughout the developing world, investment has often been funnelled away from secondary and tertiary education to support these goals. It has been argued that basic education gives a better return on investment than higher education (Psacharopoulos 1972, Psacharopoulos and Patrinos 2002). However, there are now immediate challenges in many developing countries that need to be addressed. Increased investment in research at tertiary institutions (and the subsequent training of students in research skills) would have knock-on effects in many areas of sustainable development and poverty alleviation including environmental degradation. Without a basis in sound research, effective management strategies can neither be designed nor implemented. This is illustrated by the current state of environmental and natural resource management activities in Africa, which note huge capacity gaps across scales of natural resources management (Folke *et al* 2002, Nelson 2010). Research capacity development will contribute to national development by addressing the knowledge gap between the global North and South, with the eventual aim of enabling more balanced South–North partnerships. However, it seems from the results presented here, that EO research still has a long way to go before the necessary level of equality in research is obtained to allow countries the necessary level of in-country expertise to conduct this research themselves. It also seems that we still have a situation where research is mostly done about developing countries, not by developing countries. Section 5.2 offers some practical approaches to address this issue.

5.2. Strategies for promoting collaborative EO research

There are a number of practical steps that can be taken by all EO professionals and their institutions to encourage and engage with developing country researchers. These are designed for those working in developing countries, require little economic outlay (other than time) and have the potential to increase the likelihood of meaningful results. They are by no means exhaustive, and are designed to provoke wider discussion of these issues in a practical context.

Strategy 1: focused networking. The importance of networking should never be underestimated as one of the leading means of building capacity in the developing world.

Table 2. Eleven principles of research partnerships (KFPE 1998).

1	Decide on the objectives together
2	Build up mutual trust
3	Share information; develop networks
4	Share responsibility
5	Create transparency
6	Monitor and evaluate the collaboration
7	Disseminate the results
8	Apply the results
9	Share profits equitably
10	Increase research capacity
11	Build on achievements

Society membership and conference attendance is a luxury that few can afford on a regular basis.

Action: encourage researchers to use free networking tools. Online professional networking sites are becoming increasingly common among EO professionals. For instance, LinkedIn (www.linkedin.com) is a free networking site that has an EO Network. At the time of writing this article, this network had attracted over 2400 members worldwide, many of whom are in developing countries. This service allows one to build up personal networks of current and former colleagues or contacts. It has been especially popular amongst financial professionals in the USA, but has expanded now to more than 30 million experienced professionals from around the world, representing 150 industries.

This action recommends that institutions encourage staff to use these free networking tools, and to especially encourage contacts from the developing world to join.

Strategy 2: engage teams in the complete process from an early stage. Effective collaboration is an effective means of sharing expertise, skills, data and knowledge. Beyond this, it also allows for institutional capacity building and development. The most effective capacity building is not from training courses, but from being involved with hands-on projects. Any projects or other initiatives should aim to collaborate with local institutions, and do so from the very earliest stage—that is, from the initial proposal stage. Academic researchers in developing countries are just as eager to publish as those in developed countries, and often have similar institutional and personal pressure to do so (Sawyer 2004). In this context, we recommend taking a proactive strategy to include local researchers involved with the collaboration as joint authors on papers.

The Swiss Commission for Research Partnerships with Developing Countries (KFPE 1998) outlines 11 principles for successful research partnerships, which serve as a useful framework for defining the ‘rules of the game’ when developing research collaborations (table 2).

Strategy 3: promote an ‘open’ culture. ‘Open source’ software is made available to everyone to use, modify and improve. ‘Freeware’ is software that is free to use but the source code is not available to edit. ‘Open access’ (OA)

journals are online publications that allow free access to readers but may charge authors a fee to publish.

Action: publish results in open access journals. Journal access is expensive. In developing countries it is usually prohibitively expensive, and online journals are available only through donor subscriptions. Relying on donated subscriptions is not a long-term sustainable solution. One alternative solution is to encourage researchers to submit their work to electronic open access journals. Unfortunately, there is a chicken–egg situation with OA journals in environmental sciences—they tend to have lower impact factors and therefore fewer good works tends to be submitted. However, with a concerted effort, this may change over time and perhaps emulate the incredible success that biomedical sciences have had with OA journals. There is now an OA remote sensing journal (Remote Sensing, www.mdpi.com/journal/remotesensing/) that has been running since March 2009, and many others that publish applied remote sensing research, for example Carbon Balance and Management (www.cbmjournal.com) and Environmental Research Letters (<http://erl.iop.org>).

Two points should be noted. First, while this paper is clearly written from the perspective of researchers from a developed nation working in a developing nation, many of the same principles apply generically to an EO project, whoever is conducting the research. Second, these guidelines are tailored for projects where the location country is not expected to necessarily gain from the outputs—such as terrestrial carbon dynamics, ecology, or biodiversity. The project outcomes may have secondary value to the host country, but the main purpose (and particularly the scientific justification that led to it being funded) is not country-specific. Projects aimed at addressing local user needs are more likely to be sensitive to such issues, and in particular require a much greater input from local stakeholders.

Ultimately, the work presented here is, in the first instance, aimed at influencing individual and institutional policy on working in developing countries, and secondly, influencing policy related to funding agencies who have an obligation to consider these issues in the context of the international agreements outlined above.

6. Conclusions

The importance of EO for combating current environmental problems is well recognized. By supporting the development of relevant skills, data access and processing tools, EO researchers can enhance the ability of developing countries to assess their vulnerabilities and evaluate options for adaptation. Developing countries are too reliant on external actors for conducting EO research in their own countries. From the research presented here, it appears that there are a much greater number of papers written about developing countries rather than by developing country researchers. In one example field of EO study (namely, forests) there has been no significant change in this pattern over the last 20 years, despite the increased awareness of the importance of CD within the international development community as a whole. Capacity

development in academic EO research is key for encouraging and engaging developing country researchers within the global community, and needs to become embedded as best practice across all disciplines that conduct research in developing countries.

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